# Exploring the Longwave Radiative Effects of Dust Aerosols

## How significant is it?

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*2012 Gregory G. Leptoukh On-line Giovanni Workshop*

*26 Sept 2012*

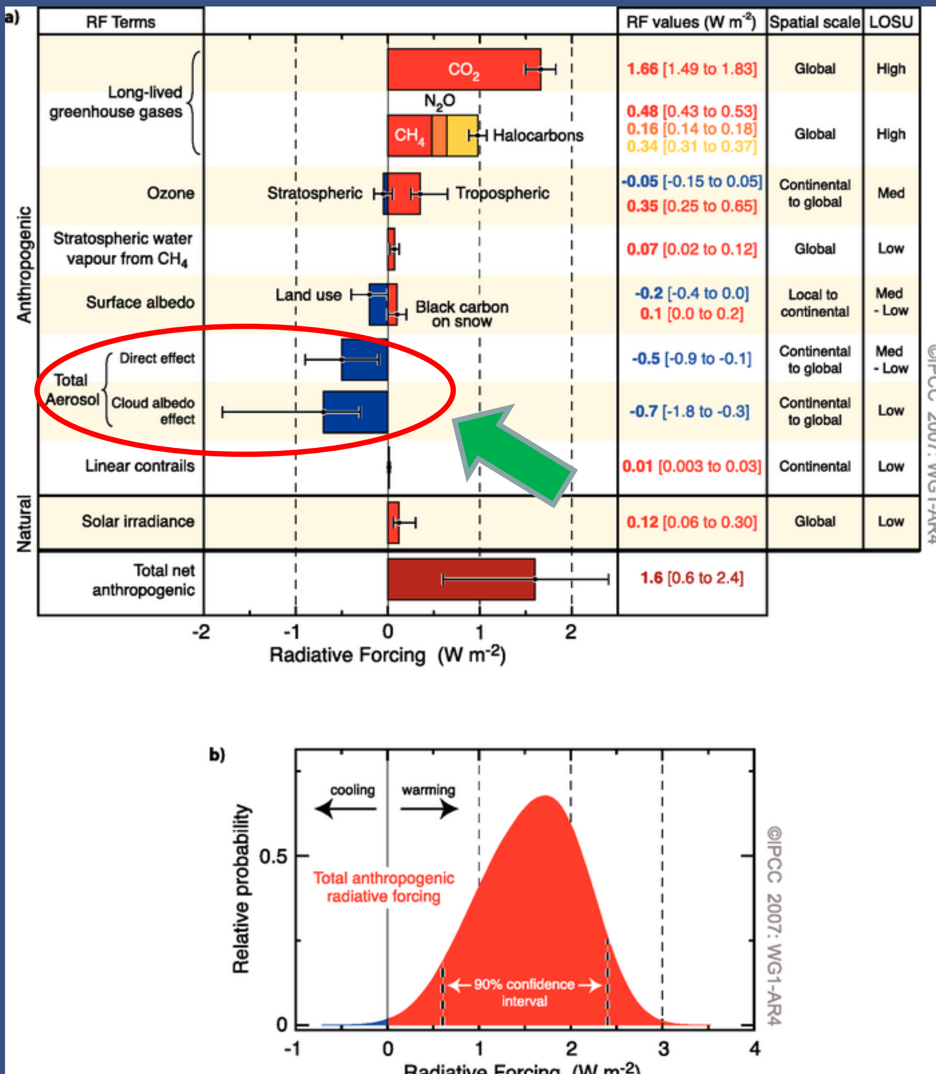
***Acknowledgements:*** *S.C. Tsay, N.C. Hsu, K.N. Liou, S. Ou, J. R. Reid, Q. Ji, T.L. Roush, B.N. Holben, E.J. Welton, Z. Li, M.J. Jeong J. Pimenta, J. Haywood, O. Kalashnikova, C. Zender, M. Mishchenko, and the SMARTLabs Team*

*Hansell, R. A., et al. (2012), An assessment of the surface longwave direct radiative effect of airborne dust in Zhangye, China, during the Asian Monsoon Years field experiment (2008), J. Geophys. Res., 117, D00K39, doi:10.1029/2011JD017370*

# *Outline*

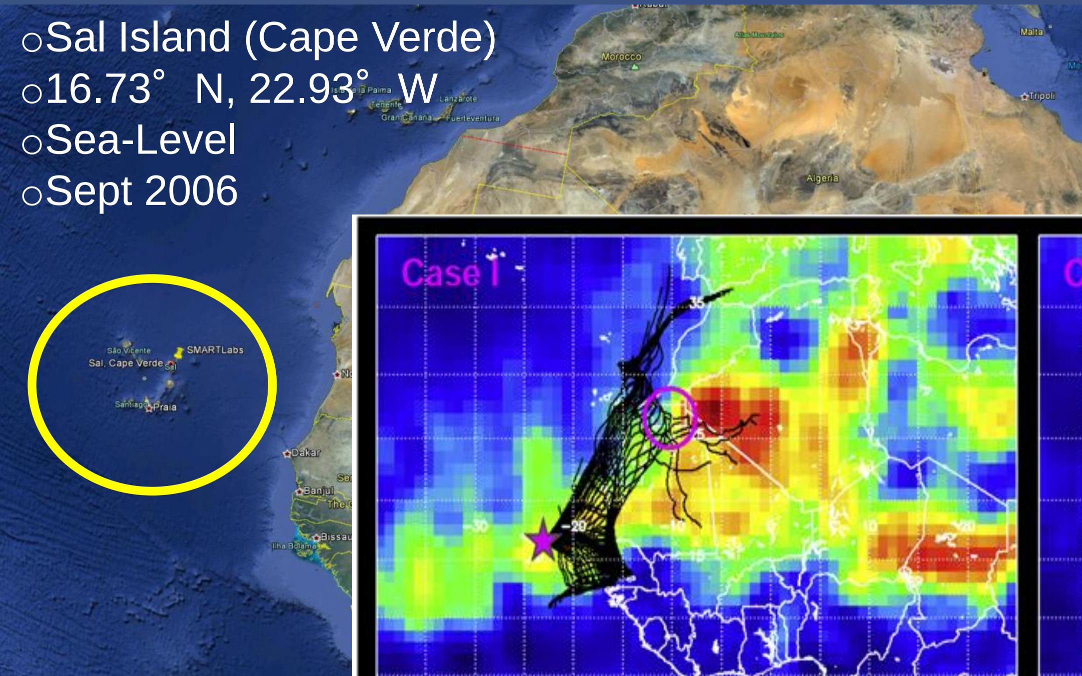
- ✓ *Motivation*
- ✓ *Field experiments*
- ✓ *Optical properties of dust*
- ✓ *Methodology*
- ✓ *Longwave Radiative Effects*
- ✓ *Summary*

# *Motivation – Big Picture*



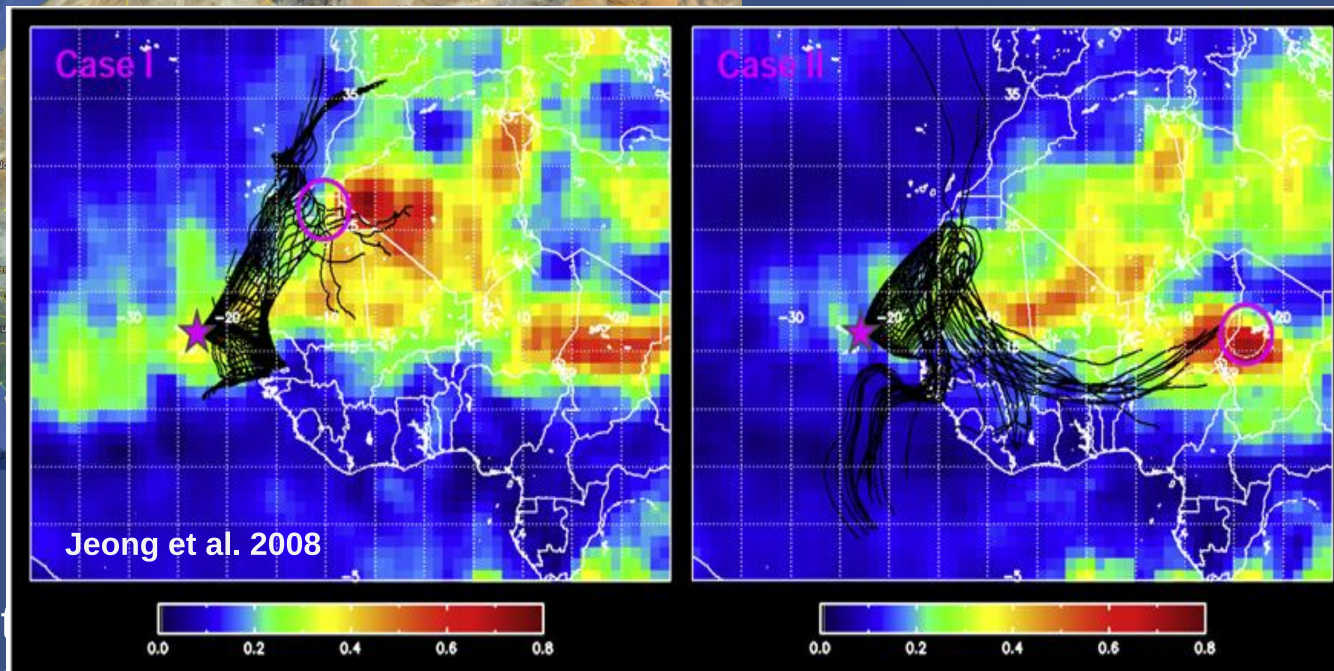

- ***<u>Aerosol radiative effects</u>*** *are uncertain in climate models*
  - *Dust is the most dominant aerosol by mass (Textor et al. 2006)*
  - *Shortwave behavior of dust is better constrained*
  - *Longwave effects of dust are not well known due to uncertainties in their optical properties*
  - *Climate models generally do not include the Longwave effects; Recent works suggest Longwave effects are important*

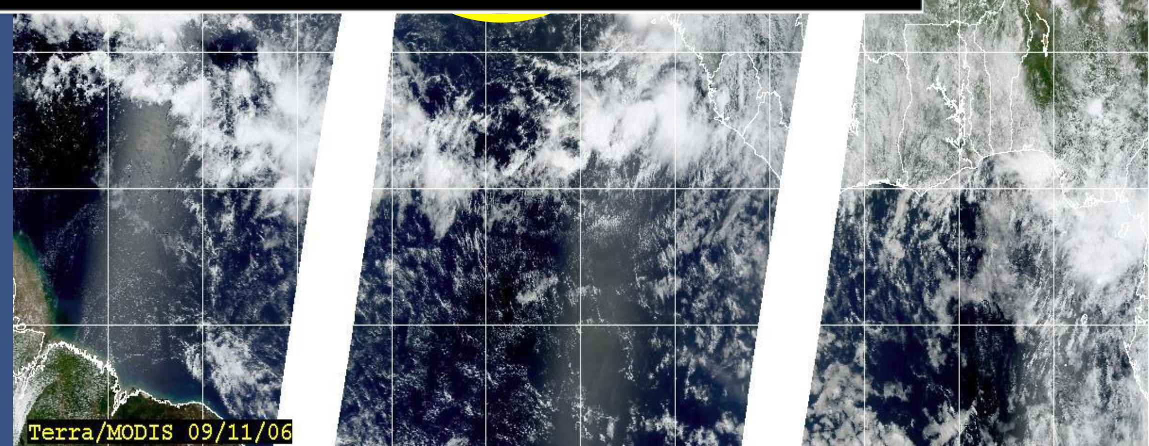
# Here I focus on 2 field experiments to study the radiative effects of dust




- Sal Island (Cape Verde)
- 16.73° N, 22.93° W
- Sea-Level
- Sept 2006

NAMMA 2006 (Zipser et al. 2006)



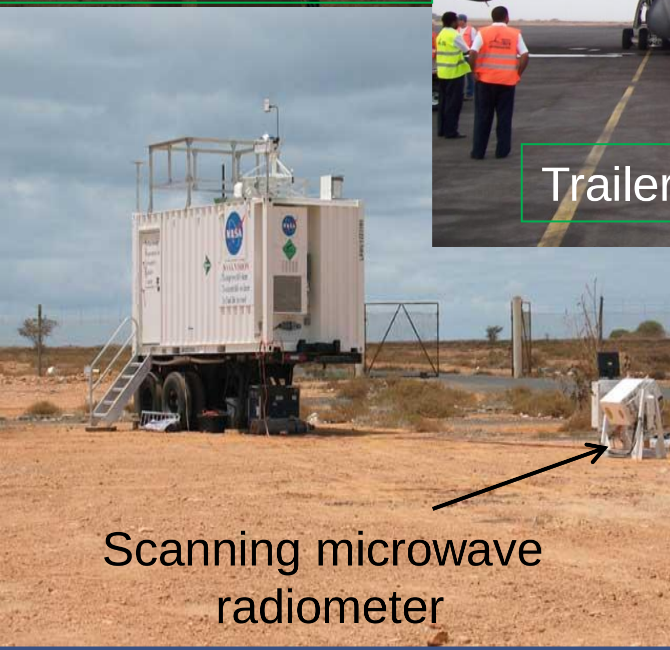




Mineral dust
African Continent mixed with
clouds during active dust period
of the field campaign

Results published in Hansell et al. (2010)

# NASA SMARTLabs at Cape Verde (Instrumentation)






**S**urface-sensing **M**easurements for **A**tmospheric **R**adiative **T**ransfer

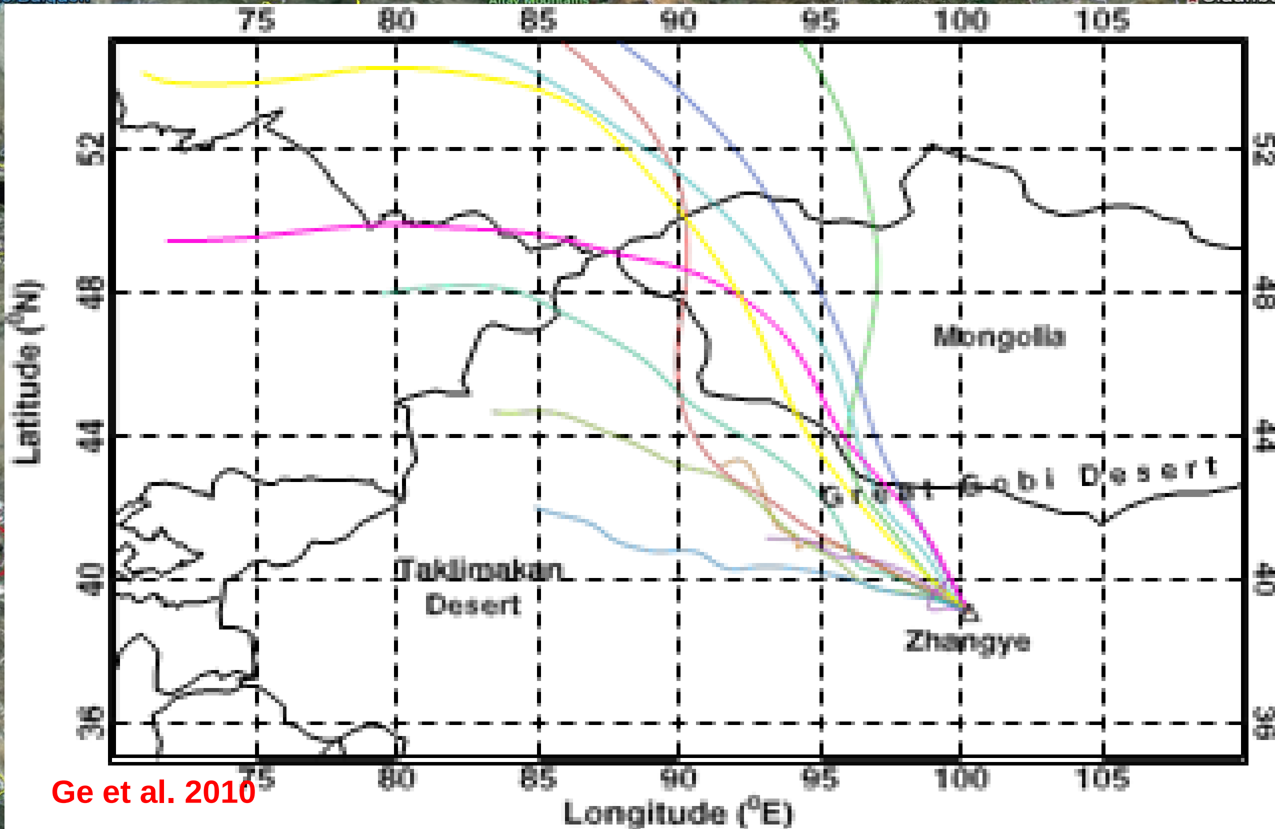
**C**hemical, **O**ptical & **M**icrophysical **M**easurements of **I**n-Situ **T**roposphere

*http://smartlabs.gsfc.nasa.gov*

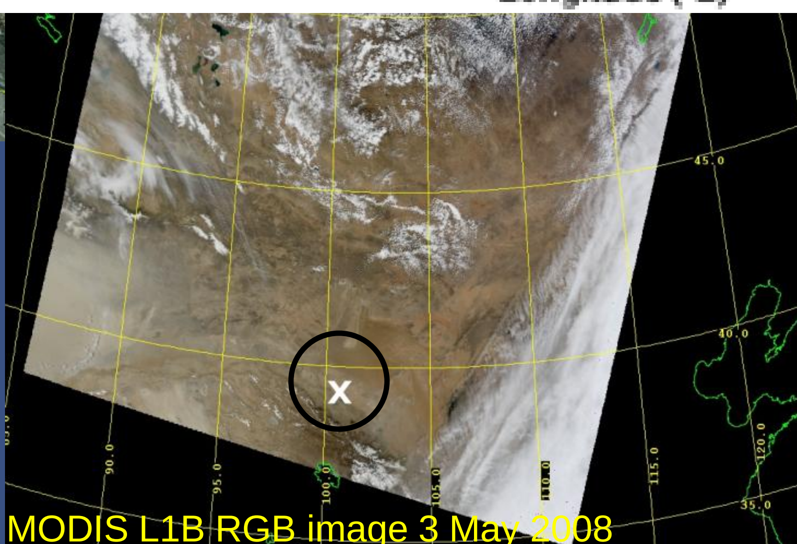
# AMY2008
(Lau et al. 2008; Li et al. 2011)

- Zhangye (desert)
- 39.0°N; 101°W
- 1.5 km ASL
- April-June 2008

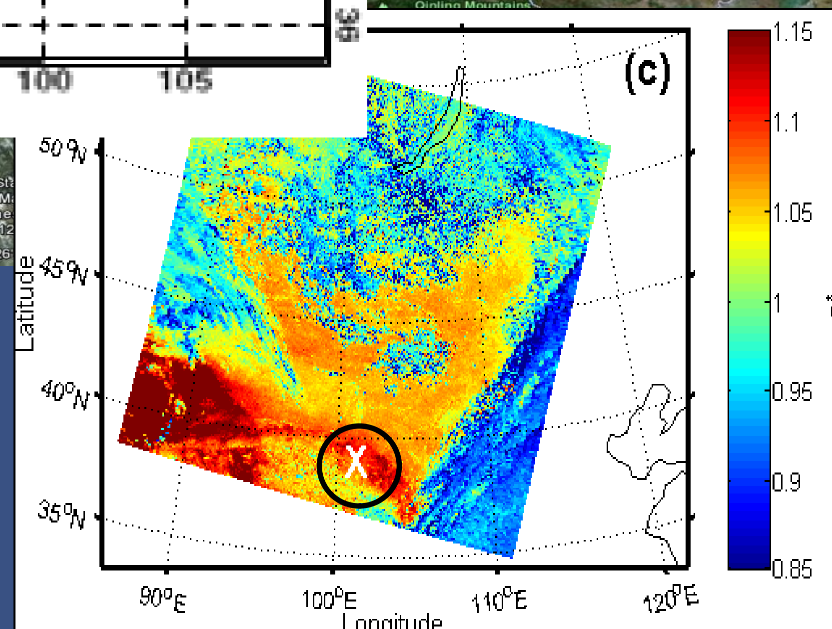
Circles mark location of Zhangye and NASA SMARTlabs instruments



Ge et al. 2010

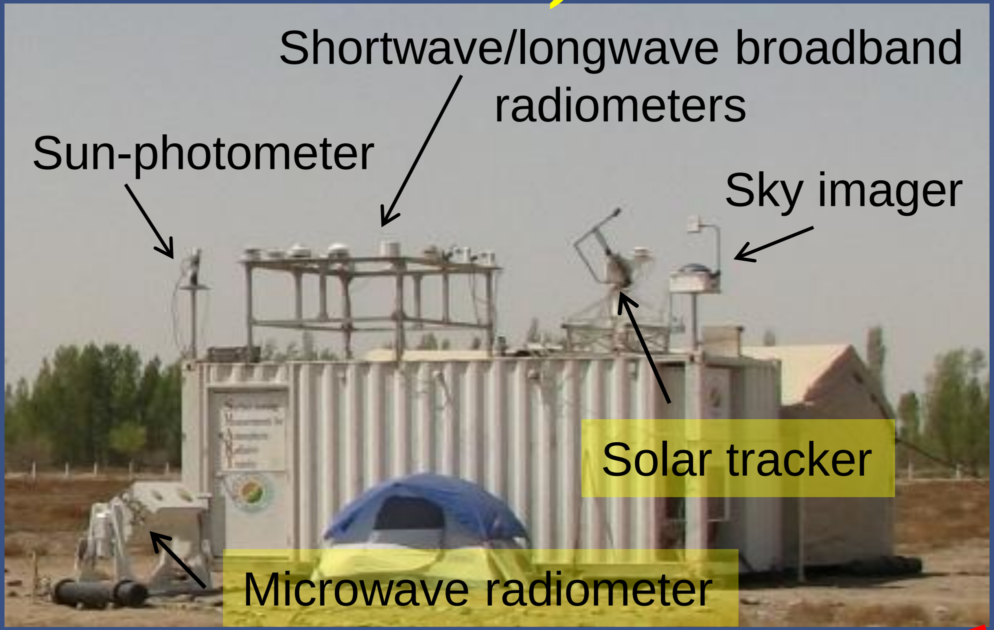


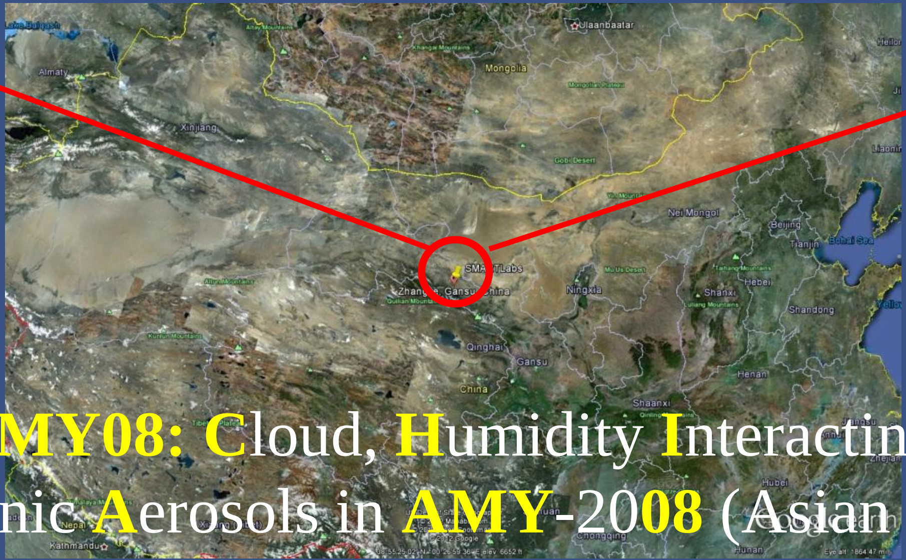
MODIS L1B RGB image 3 May 2008



Dust Parameter (D* - Hansell et al. 2007)

# NASA SMARTLabs at Zhangye China (Instrumentation)

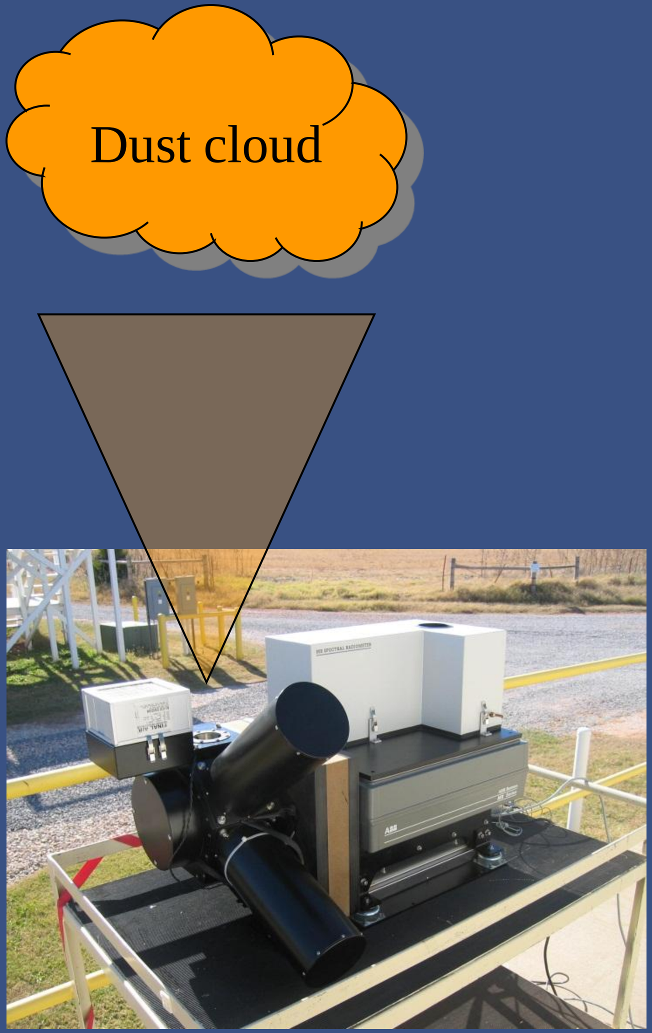




**CHINA$^2$-AMY08: C**loud, **H**umidity **I**nteracting **N**atural/ **A**nthropogenic **A**erosols in **AMY**-20**08** (Asian Monsoon Years)

# Spectral Interferometry

- Passive, fully automated, ground-based interferometer
  - Measures downward emissions
- Micheleson Series MR100 (Bomem)
- 2 detectors:
  - InSb: $3.3\mu m \leq \lambda \leq 5.5\mu m$
  - MCT: $5.5\mu m \leq \lambda \leq 19\mu m$
- 2 Blackbody references
  - Ambient /Hot (60°C)
- Scene mirror optics assembly
- Temporal frequency: $\cong$ 10min (BB + scene + BB)
- 1 $cm^{-1}$ spectral resolution



# Courtesy: NASA Giovanni System

Giovanni allows for rapid assessment of regional aerosol conditions

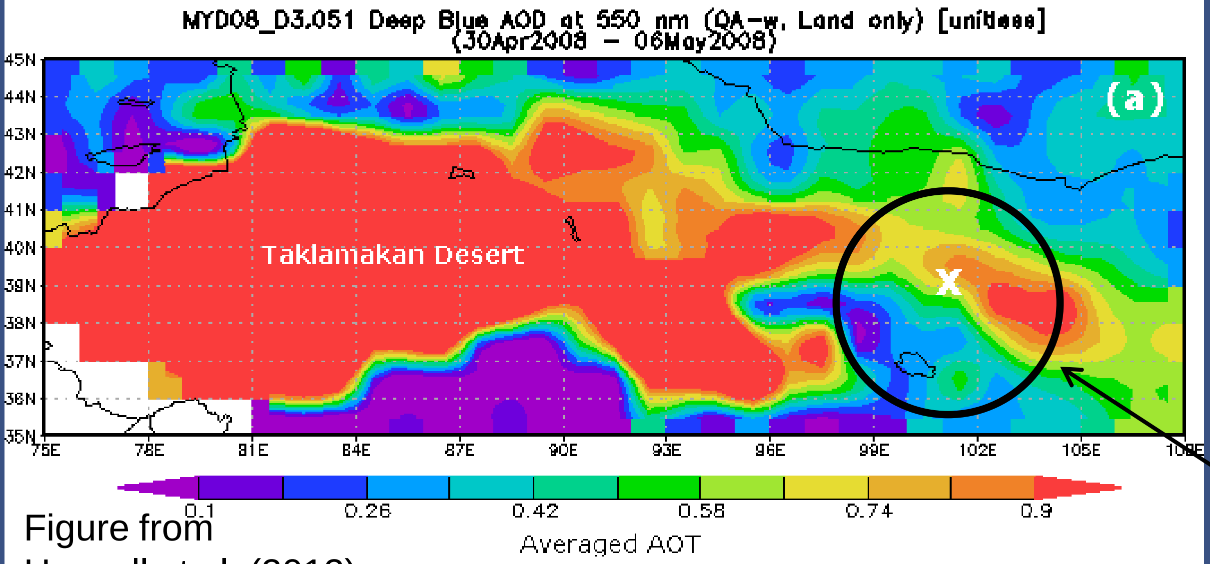
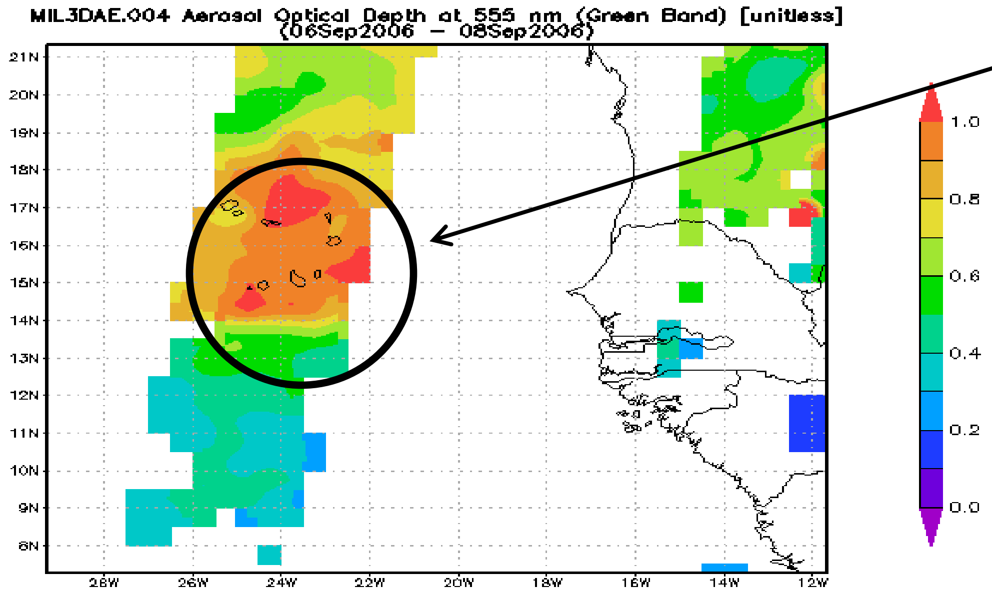



Figure from
Hansell et al. (2012)

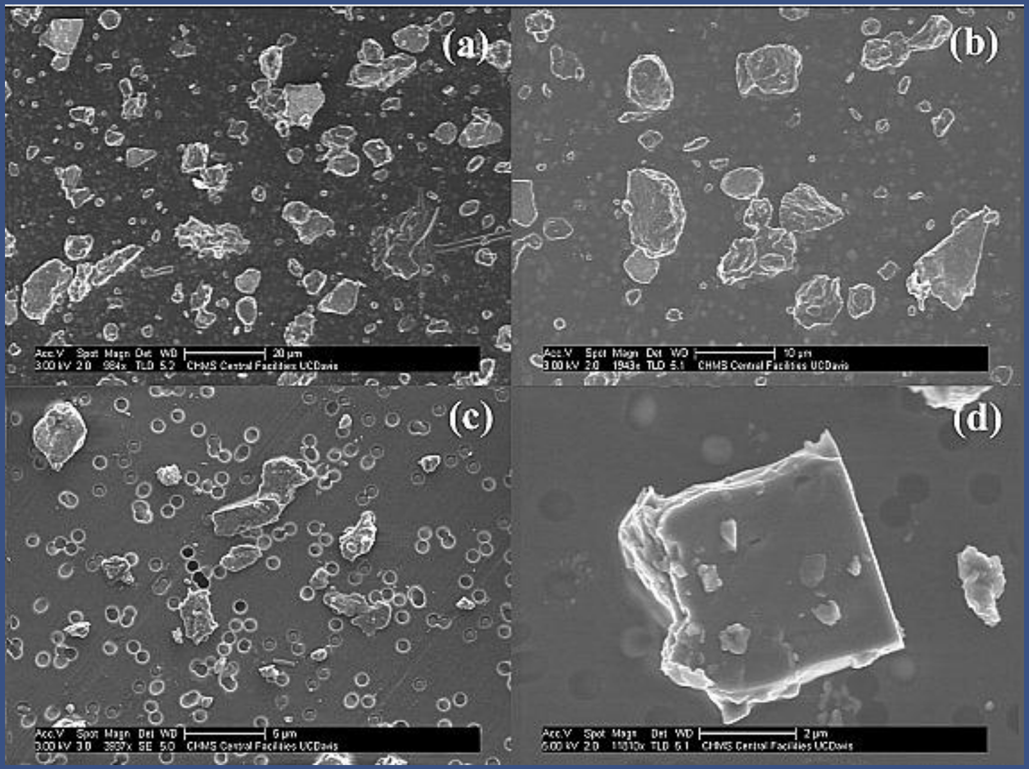
Deep Blue averaged AOT from (30 April –6 May 2008) at Zhangye during AMY.

SMARTLabs



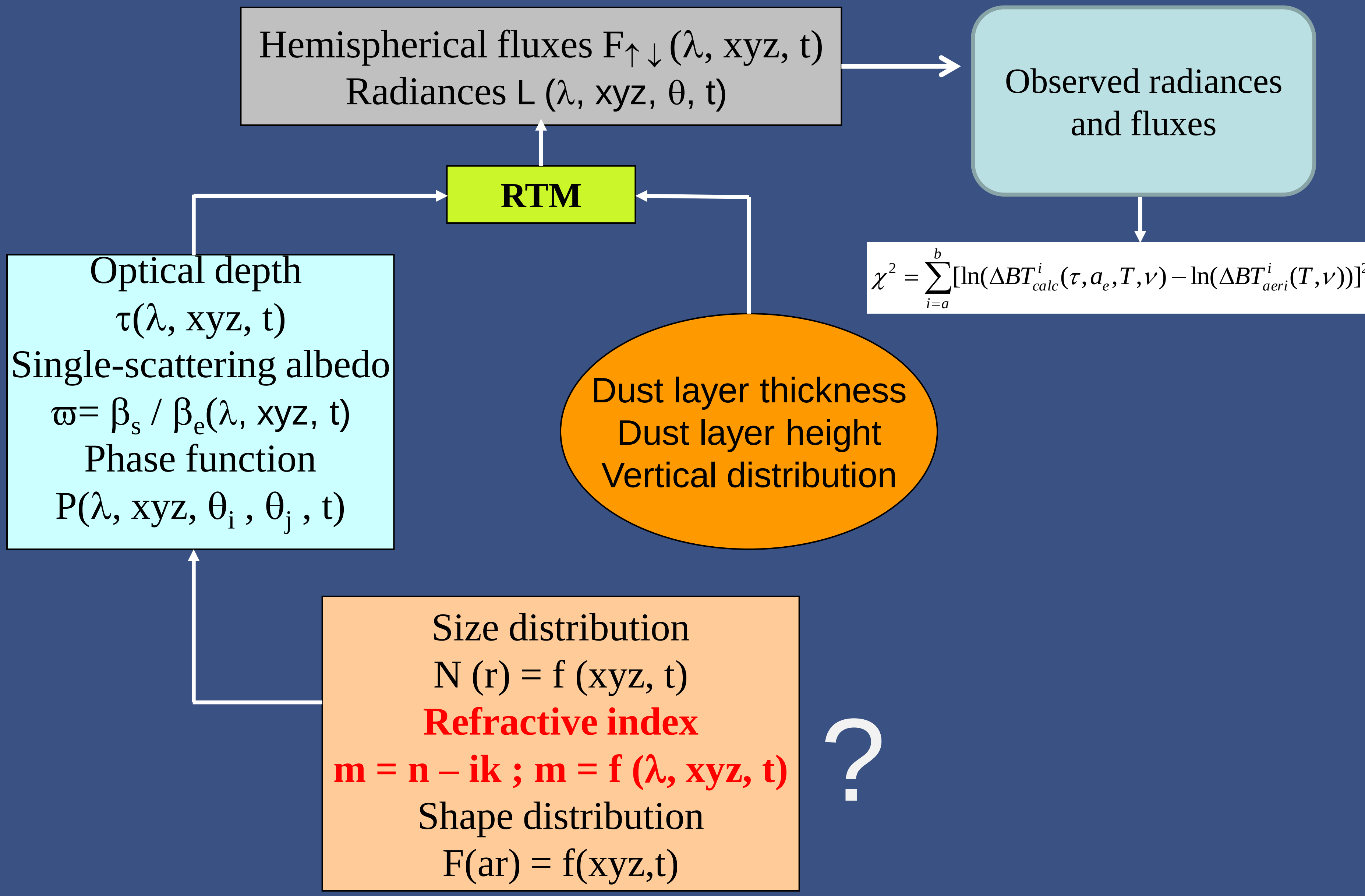

MISR averaged AOT from (6–8 Sept 2006) at Cape Verde during NAMMA.

# Dust Physicochemical Properties: Optical Model

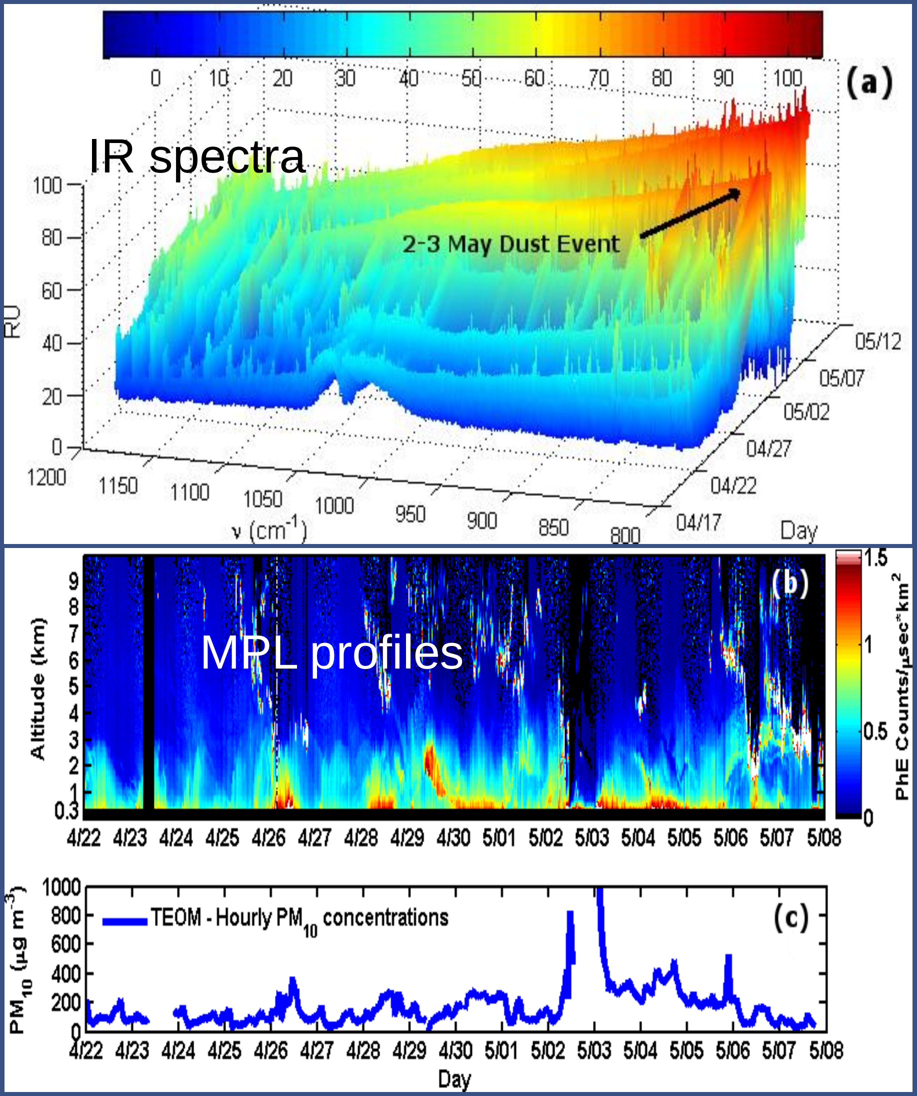



SEM image provided by Dr. J.S. Reid

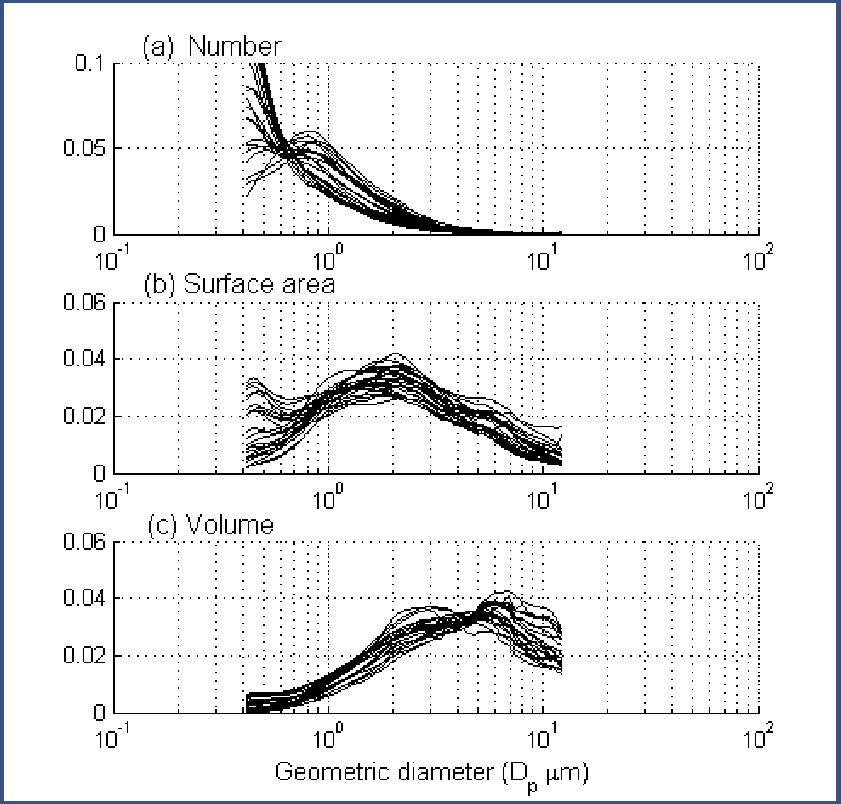
# Dust model parameterizations



# Local measurements: model constraints

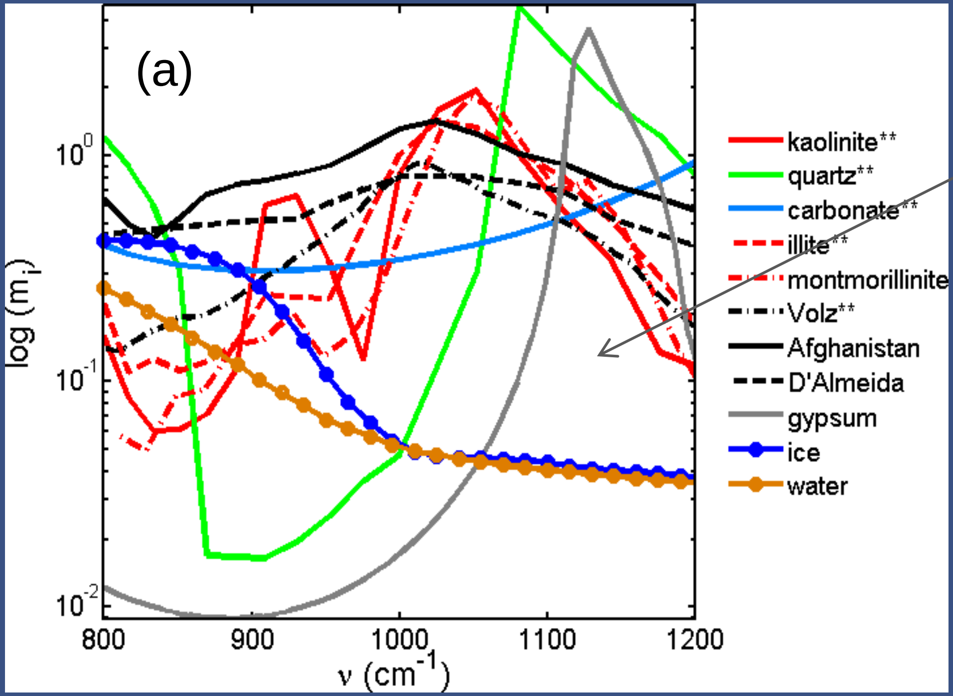



Particle size spectra

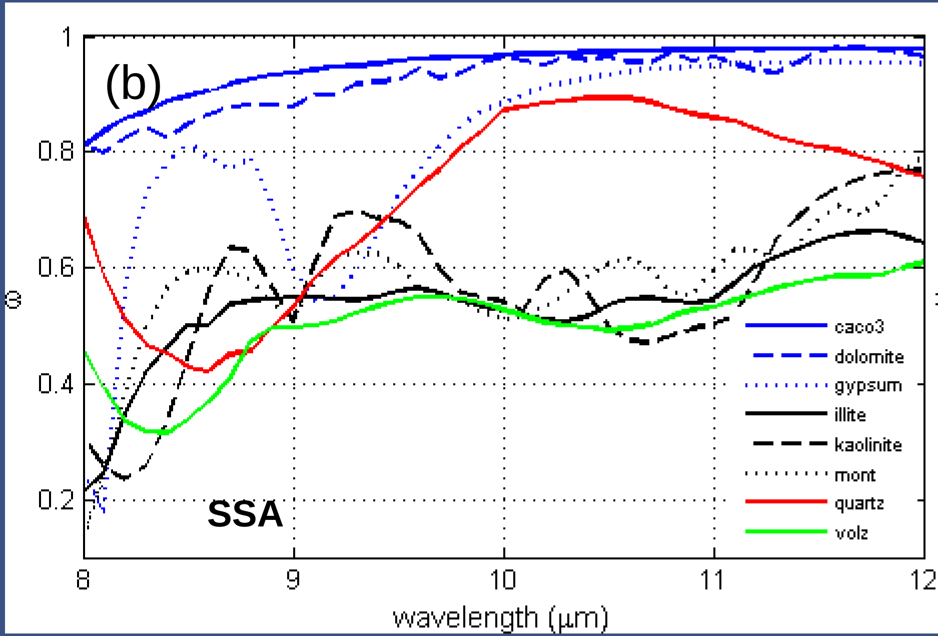


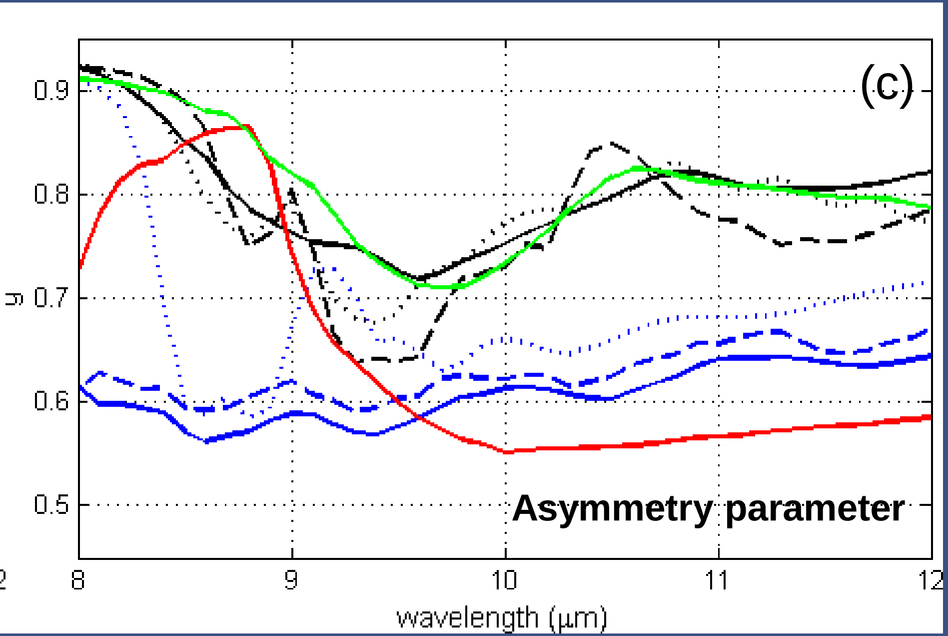

PM10 mass concentrations

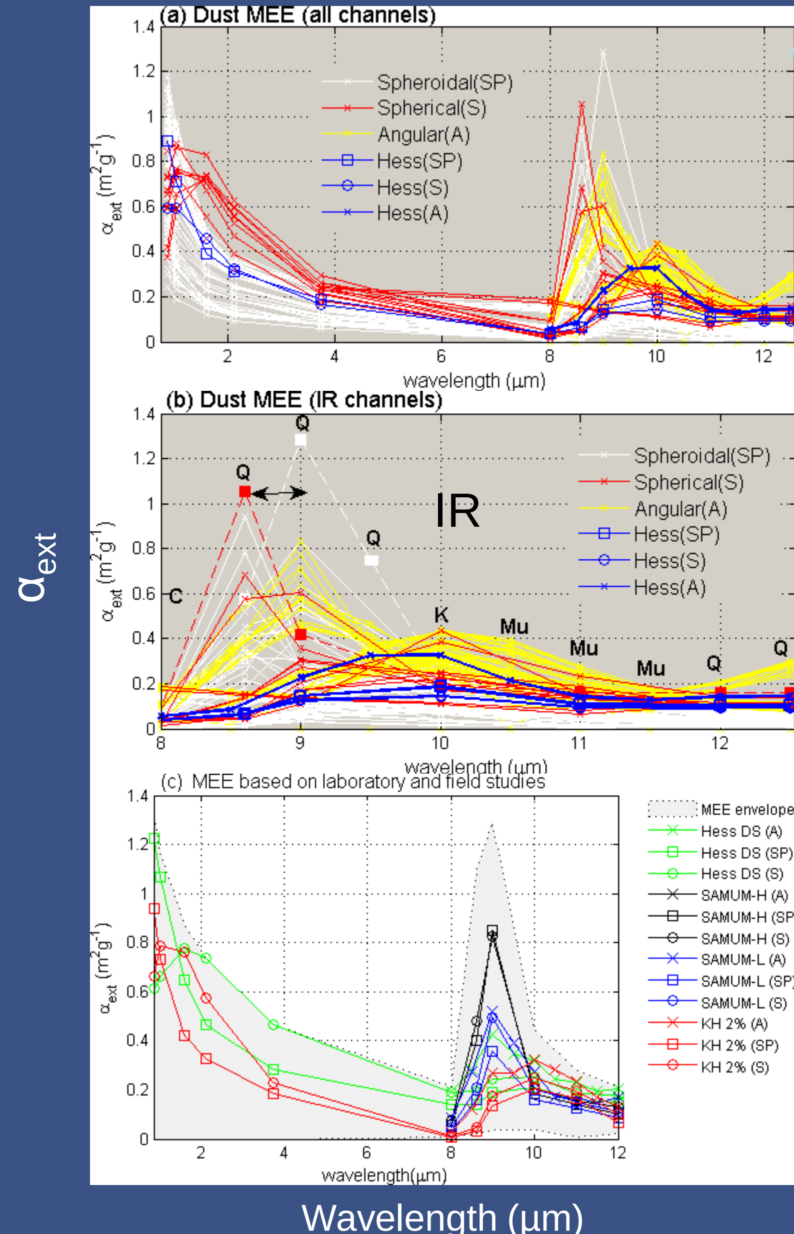
Hansell et al. 2012

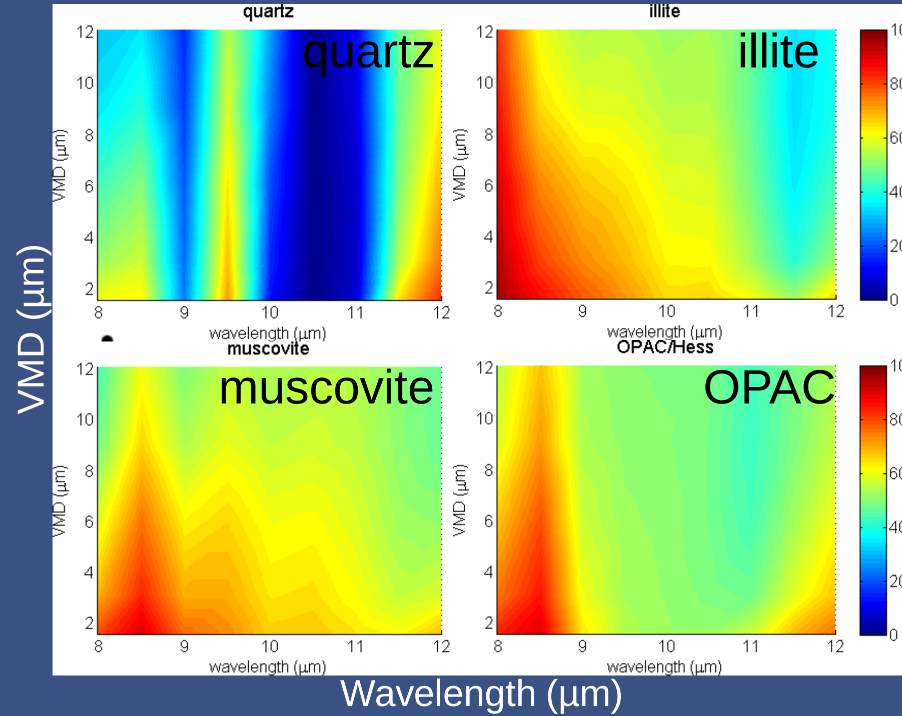



- Optical constants of common terrestrial minerals in the thermal IR (imaginary term)
- Large variability in absorptive peaks are evident in the single-scattering properties below
- Dust composition plays large role in LW applications






- ❑ Absorption in the IR bands
- ❑ Spectral envelope of mass extinction efficiencies of dust versus composition, shape, and size

# Key optical parameters in thermal IR

Hansell et al. 2011

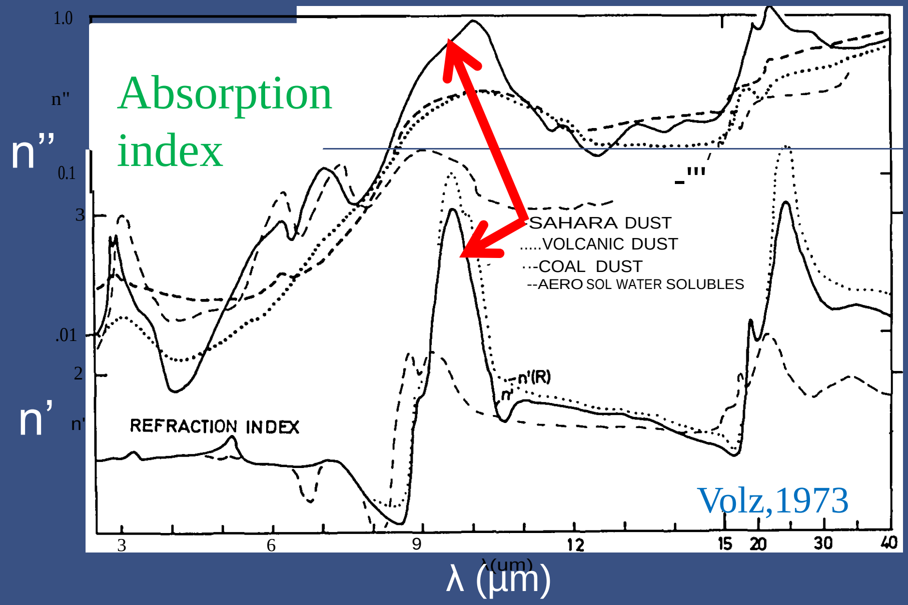
| *Jeong et al.* [2008] | Current study | Data source |
|---|---|---|
| Quartz (41%) | Quartz (43%)[1] | Gray (1963), Drumond (1935), Spitzer & Kleinman (1961), Philipp (1985), Longtin et al. 1988 |
| Plagioclase (17%) | Anorthosite (17%) | *J.R. Aronson and P.F.Strong* [1975] - LW |
| K-Feldspar (9%) | Andesite (8%)[1] | *Pollack et al.* [1973] - SW |
| Calcite (10%) | Calcite (10%) | *Long et al.* [1993] - LW<br>*Marra et al.* [2006] - SW |
| Mica (12%) | Mica (12%)[2] | *Aronson and Strong* [1975] - Muscovite (LW)<br>*Egan and Hilgeman* [1979] - Illite (SW) |
| Chlorite (10%) | Chlorite (10%) | *Mooney and Knacke* [1985] - LW<br>*Thomas et al.* [2009] - SW |
| Amphibole (1%) | Amphibole (0)[1] | No data available[1] |
| Dolomite (0) | Dolomite (0) | N/A[3] |
| Gypsum (0) | Gypsum (0) | N/A[3] |
| Total – 100% | Total – 100% | N/A[3] |

Adapted from Jeong et al. 2008

Table from Hansell et al. 2012

# Zhangye

- In-situ mineralogical measurements at Zhangye
- Birefringence properties

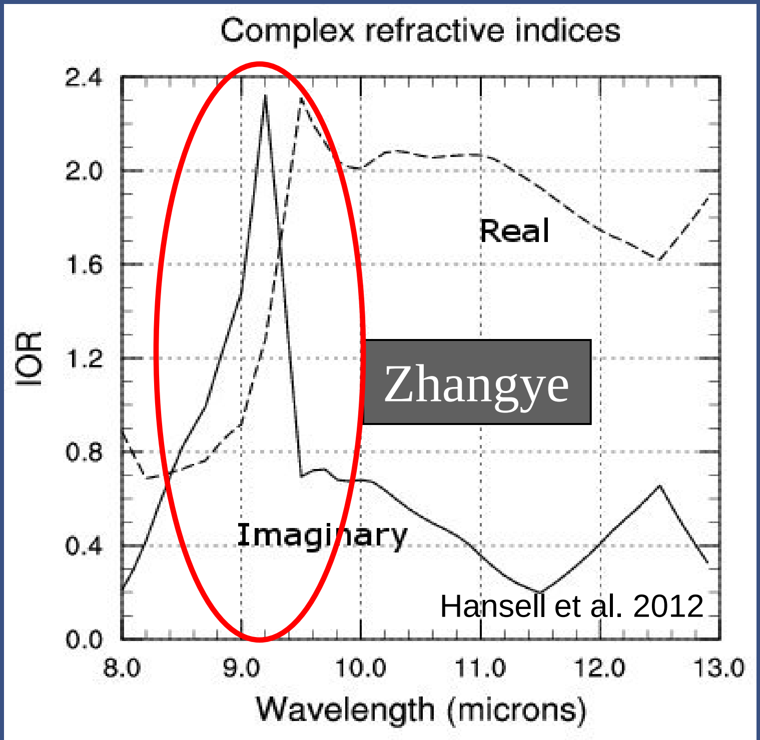


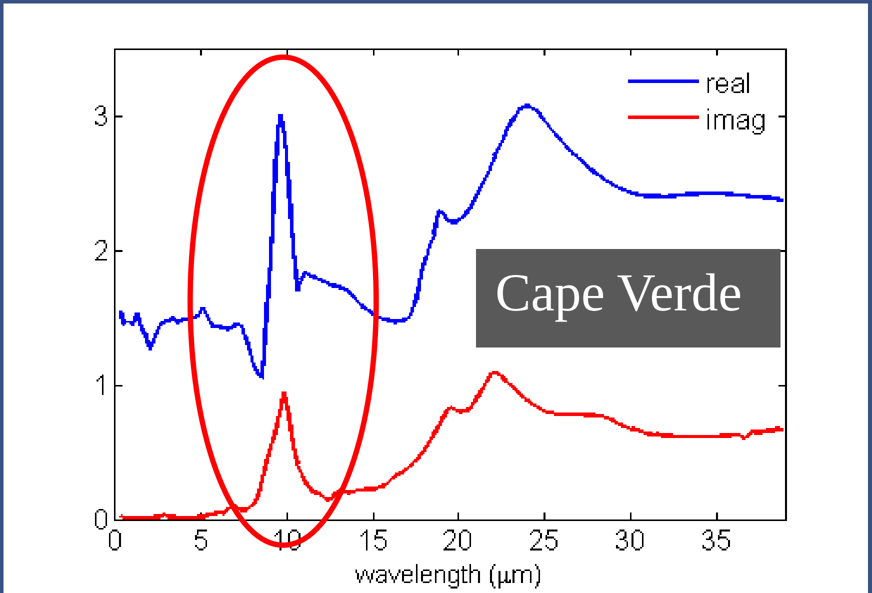

# Cape Verde

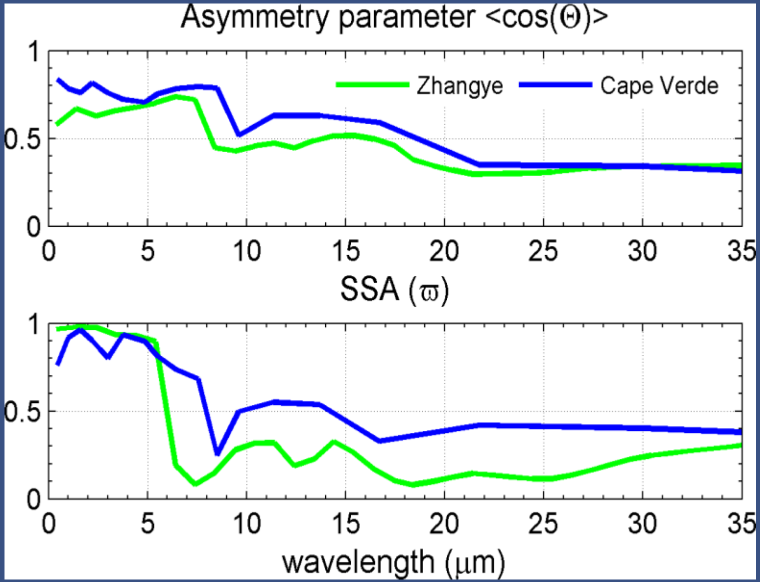
- Transported Saharan dust at Cape Verde
- Clay , illite, kaolinite, and quartz traces
- IOR: local AERONET climatology, Volz (1973) and D' Almeida (1991)
- Birefringence properties

# Mineral composition – optical constants

# Dust Models



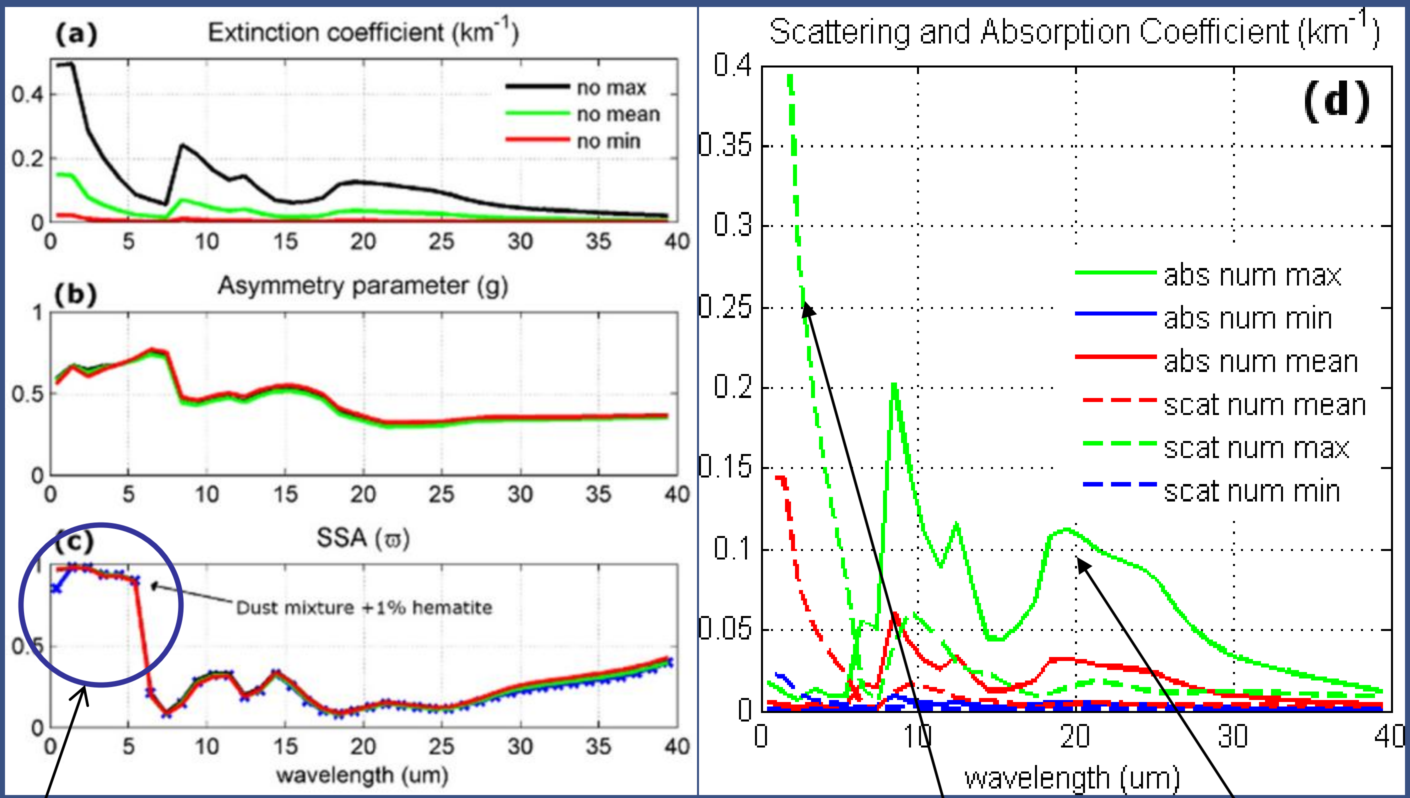




Zhangye

CapeVerde

# Zhangye optical model

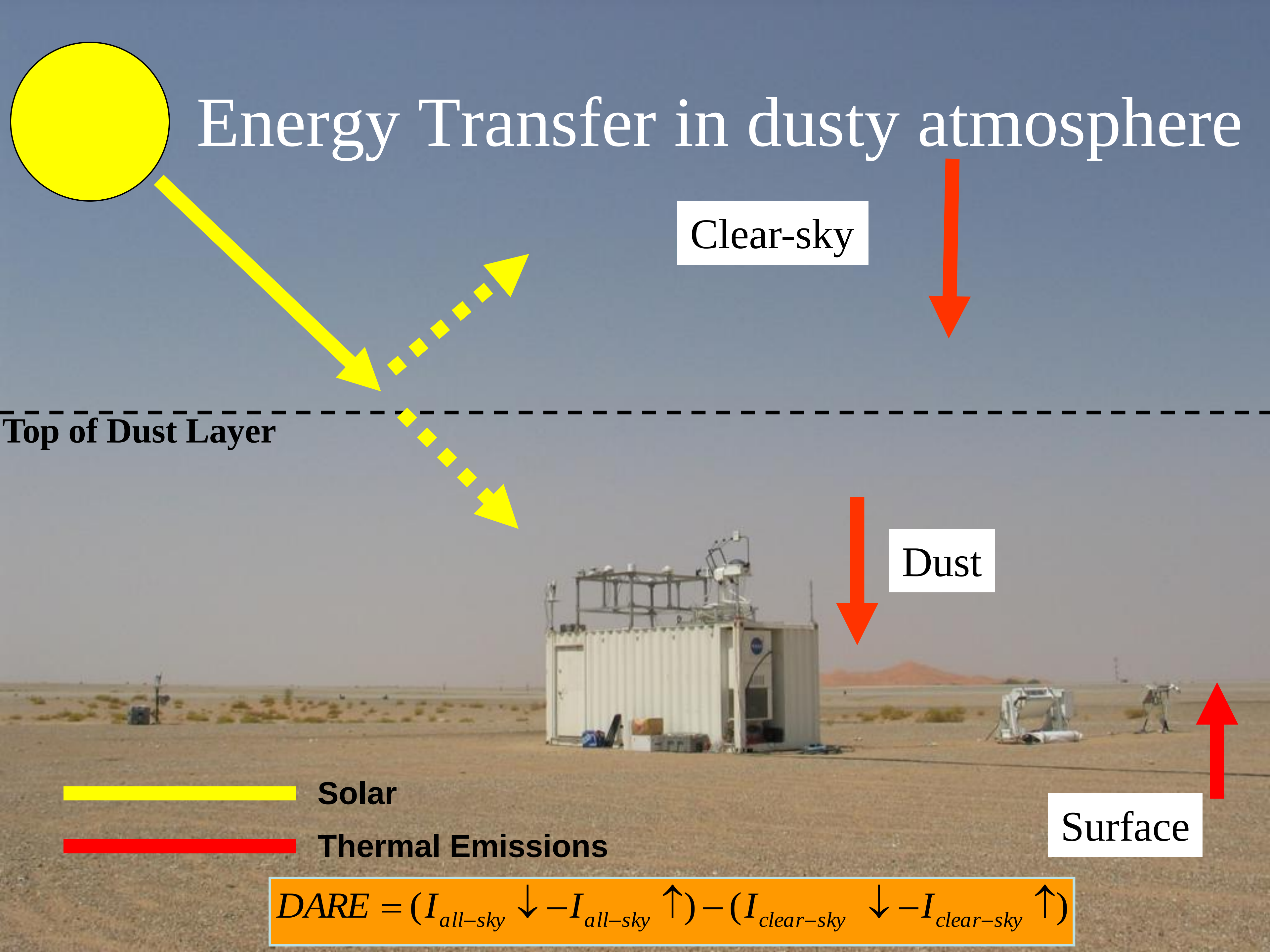



Hematite mixture (~1%)
SSA↓ ~ 5-10%

Larger scatter

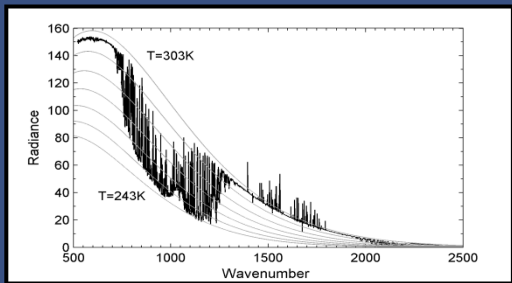
Larger absorption

Hansell et al. 2012



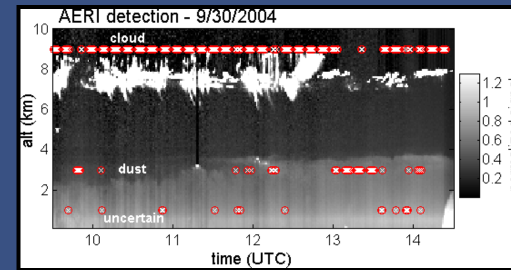
Energy Transfer in dusty atmosphere
Clear-sky
Top of Dust Layer
Dust
Surface
Solar
Thermal Emissions
$$DARE = (I_{all-sky}\downarrow - I_{all-sky}\uparrow) - (I_{clear-sky}\downarrow - I_{clear-sky}\uparrow)$$

# Methodology




AERI LW spectrum

Radiance correction spectrum




Cloud screen (BT11μm-BT10μm)

AOT retrieval (Scaled to visible)

AERONET

LW radiometer PIR

Broadband RTM

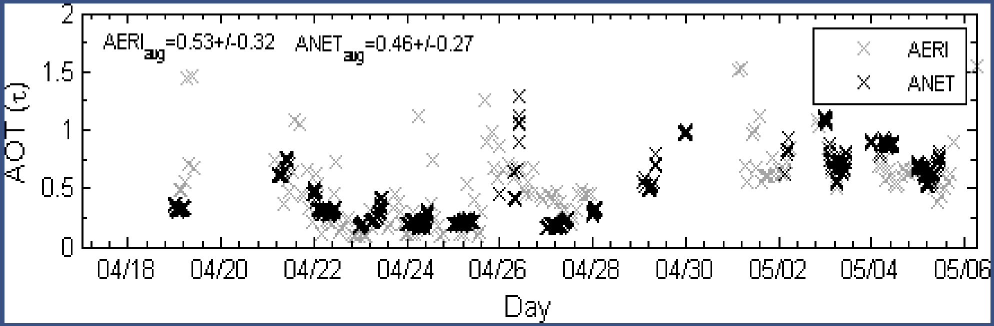
AERIPLUS + sounding profiles

Dust optical model

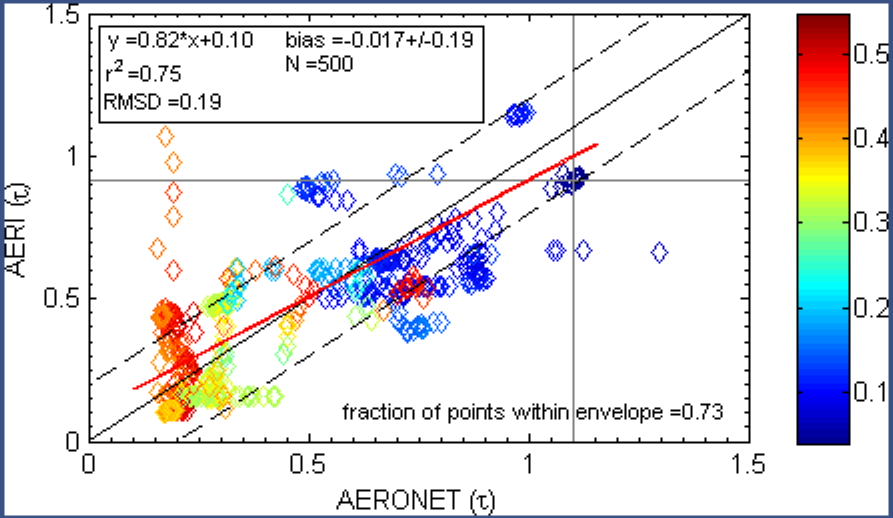
$DRE_{LW}$

Hansell et al. 2012

# AOT Retrievals




Zhangye

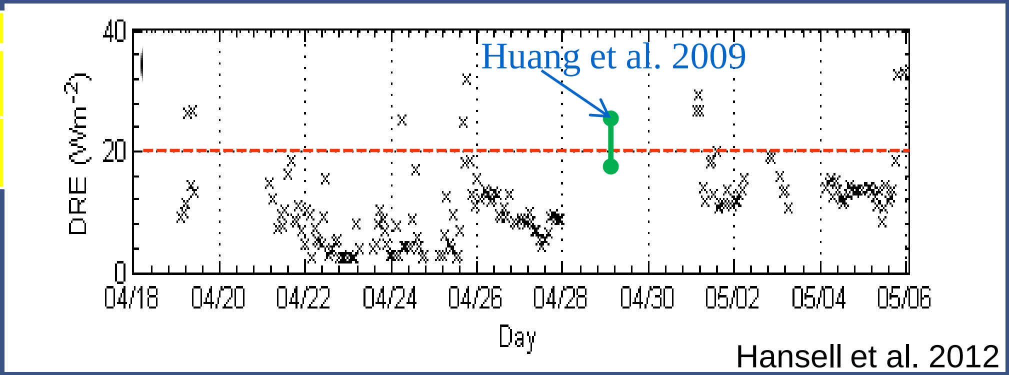



- Average visible AOT (0.55μm) ~0.53 ±0.32.
- Daytime/nighttime loading is comparable

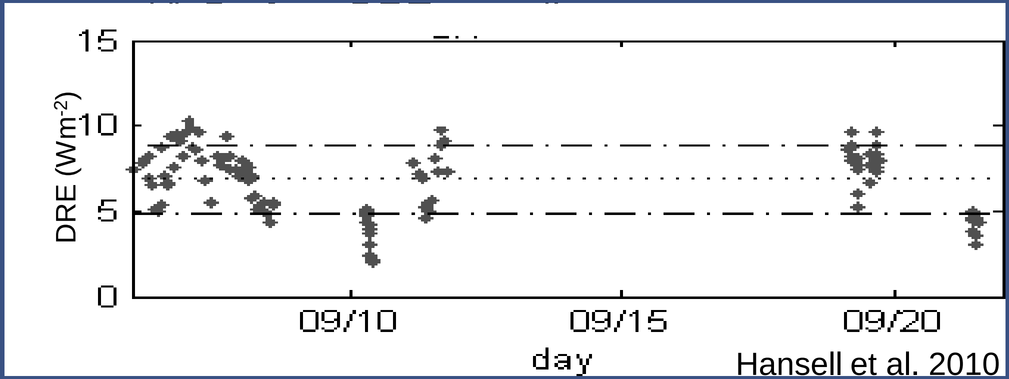
Hansell et al. 2012

# Instantaneous Surface DARE

| |
|---|
| **Avg Total = 10.1 ± 4.9** |
| **Avg April = 10 ± 7** |
| **Avg May =18 ± 8** |




- Zhangye DARE: ~2-20 Wm$^{-2}$



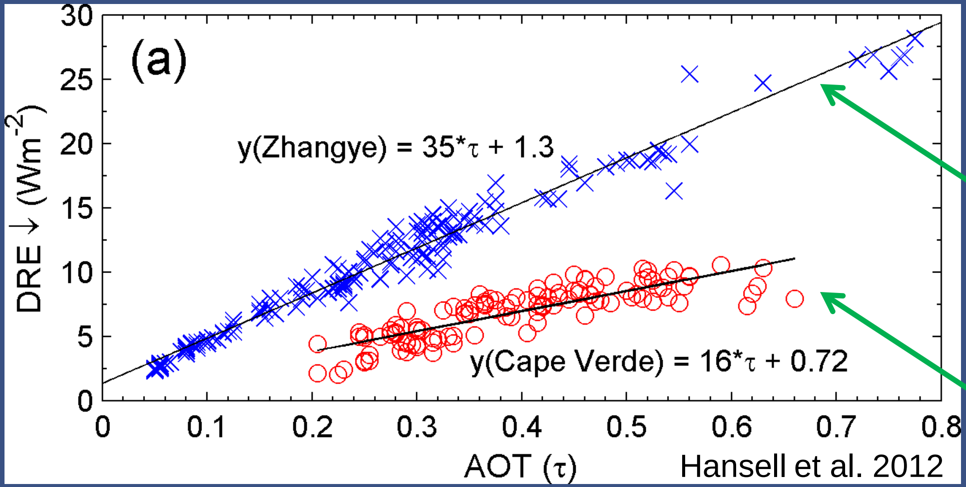

- Cape Verde DARE: ~2-10 Wm$^{-2}$

| |
|---|
| **Avg Total = 6.4 ± 2** |

DARE (Zhangye) ~ 2X larger than that at Cape Verde!

- The upper end of DARE is comparable to modeled and observed Cloud Radiative Effects (≥30 Wm$^{-2}$ - e.g., *Lockwood*, 1992); Thus it is climatically significant.

# Surface DARE (Efficiency)

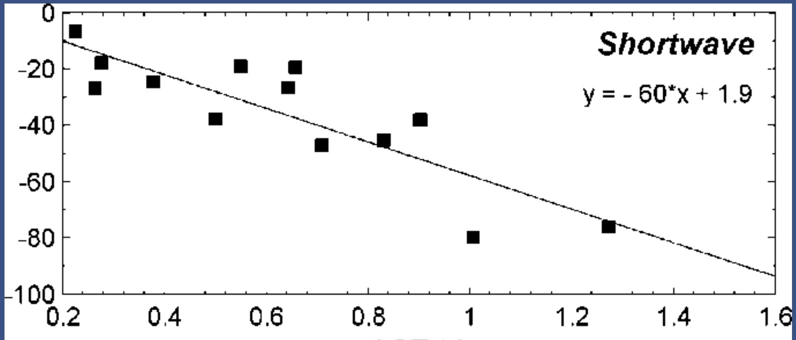





- DARE (Zhangye) ranges from 31-35 $Wm^{-2}\tau^{-1}$
- DARE (Taklamakan) ranges from 18-39 $Wm^{-2}\tau^{-1}$ (Xia et al. 2009)
- DARE (Zhangye) ~ 2X larger than that at Cape Verde

# Surface $DARE_{SW}$

- Haywood et al. 2003 estimated $DARE_{SW}$ = -209 $Wm^{-2}$ during SHADE field campaign (around Cape Verde)
- Diurnally averaged $DARE_{SW}$ ~ -38.4 $Wm^{-2}\tau^{-1}$ (Anderson et al. 2005)
- Considering meteorological and dust conditions to be comparable during both field studies (in September), the *derived $DARE_{LW}$ (over ocean) from NAMMA is ~42%* of the diurnally averaged $DARE_{SW}$ measured during SHADE.



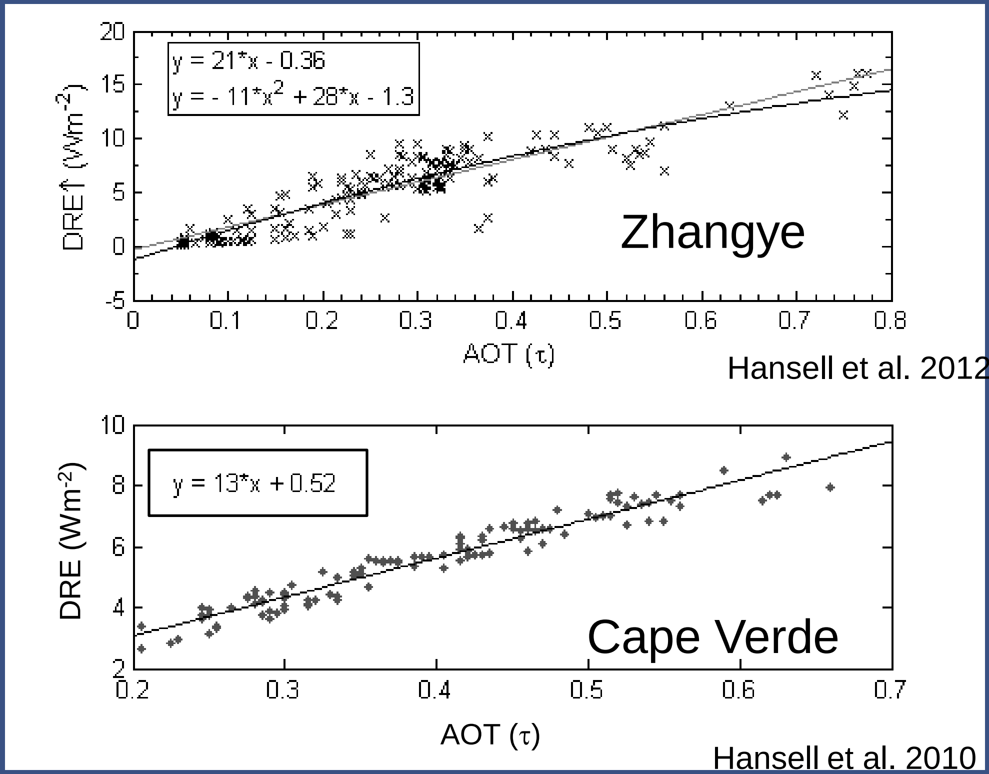
Hansell et al. 2012

$$DRE_{SW} = \frac{1}{24} \int_{sunrise}^{sunset} IDRE_{SW}(H)\,dH$$

- ❑ LW significance (Zhangye) ranges from *51-58% of the SW effect*
- ❑ Over one half of SW cooling is compensated by LW warming
- ❑ Larger than the 33% compensation reported by Huang et al. 2009, but very close to what was found by Xia et al. (2009) - ~58%.

❑ *Level of significance tied to how well SSA can be constrained*

# TOA DARE (Efficiency)

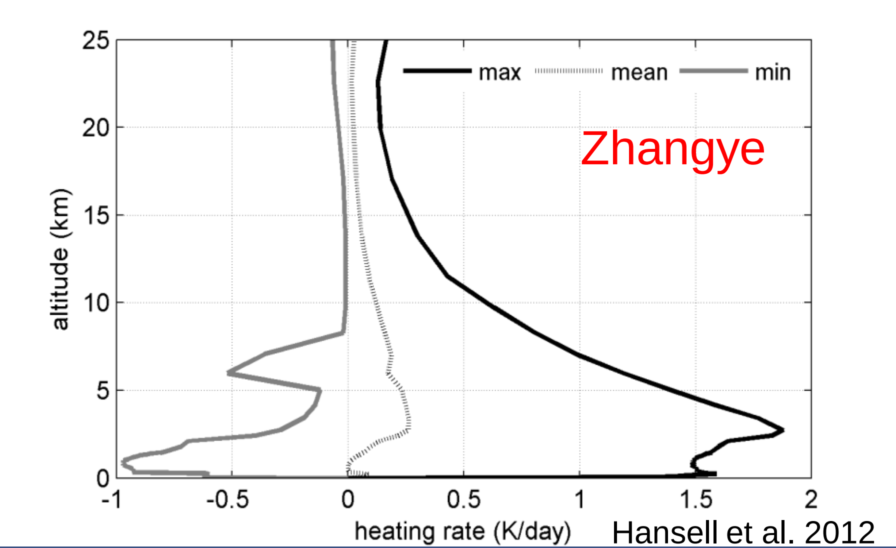



DARE ~ 20 $Wm^{-2}\tau^{-1}$

DARE ~ 13 $Wm^{-2}\tau^{-1}$

- LW flux enhancement at surface is seen as a reduction in the OLR due to absorption by intervening dust layers
- TOA DARE ~60% larger at Zhangye

# Heating Rates



Hansell et al. 2012

- 0.25-0.30 K/day on average, with maximum heating reaching over 1.5 K/day

*Huang et al.* [2009], using CALIPSO derived vertical distributions of dust extinction over Taklamakan Desert (July 2006), reported heating rates that varied between 1-3 K/day depending on dust load, with maximum heating reaching 5.5 K/day.

# Summary Highlights

- Cape Verde: Surface $DARE_{LW}$ varied ~2-10 $Wm^{-2}$, with daytime/nighttime means of 6.9 and 8.4 $Wm^{-2}$, respectively.
- Zhangye: Conservatively, surface $DARE_{LW}$ varied about 2-20 $Wm^{-2}$, with daytime/nighttime means of ~12.0$Wm^{-2}$. Was found to be as high as ~28 $Wm^{-2}$
- Cape Verde: $DARE_{LW}$ efficiency ~16 $Wm^{-2}\tau^{-1}$, and nearly 42% of the diurnally averaged SW values measured during SHADE
- Zhangye: $DARE_{LW}$ efficiency ~35 $Wm^{-2}\tau^{-1}$, and can be as high as 58% of the diurnally averaged observed SW values.

# Summary (Cont'd)

- Cape Verde: TOA $DARE_{LW}$ varied ~2 - 11 $Wm^{-2}$. The $DARE_{LW}$ efficiency at TOA is ~13 $Wm^{-2}\tau^{-1}$.
- Zhangye: TOA $DRE_{LW}$ varied ~2 - 16 $Wm^{-2}$. The $DARE_{LW}$ efficiency at TOA is ~20 $Wm^{-2}\tau^{-1}$.
- Certainly non-negligible, the surface $DARE_{LW}$ can be an important parameter for assessing regional changes in surface temperatures, moisture budgets, and being able to modulate the dynamics of the atmosphere.
- The upper end of DARE is comparable to Cloud Radiative Effects ($\geq$30 $Wm^{-2}$); Thus it is climatically significant.

- At regional scales near dust source regions, DARE in the LW is important and can leverage the impact of SW cooling.

Thank you!